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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Manned Lunar Program Options Mission Modes

TM- 67-1012-5

DATE- May 5, 1967

FILING CASE NO(S)- 232

AUTHOR(S)- C. Bendersky
D. R. Valley

FILING SUBJECT(S)- Lunar Mission Options
(ASSIGNED BY AUTHOR(S)- Augmented LM

ABSTRACT

This memorandum presents the results of an investigation of mission modes for lunar exploration. The inventory of equipments (transportation and mission equipment) was assembled into a variety of different mission modes selected on the basis of hardware availability, use of Apollo technology, and cost effectiveness.

Landed payload capabilities for each of the modes were computed using a range of ΔV requirements. These capabilities are presented for the following mission modes along with a brief discussion of the anticipated problem areas:

I. SINGLE VEHICLE MISSION USING AVAILABLE OR MINIMUM MODIFICATION EQUIPMENT

1. Apollo mode with relaxed ΔV budget
2. Extended Staytime Apollo (Augmented LM)
3. Earth Orbit Rendezvous Mode

II. TWO-VEHICLE MISSION USING AVAILABLE OR MINIMUM MODIFICATION EQUIPMENT

1. Unmanned Apollo with LM Landing

III. MISSION MODES USING NEW OR MODIFIED EQUIPMENT

1. Intermediate Launch Vehicles
2. LM Shelter Mission
3. LM Truck/ELS Mission
4. S-IVB Stage Converted to Lander (LASS)
5. Service Module Lander

[redacted]

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FROM: C. Bendersky
D. R. Valley

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TECHNICAL MEMORANDUM

1.0 INTRODUCTION

The transportation and mission equipment included in this study were assembled into an assortment of different mission modes to accomplish varying levels of lunar exploration. Effort was concentrated on the assessment of options suitable to the time span between the Apollo Applications Program (AAP) and establishment of a semi-permanent lunar base. As a result, mission modes associated with the AAP (Shelter-Taxi) and the large scale concepts (LESA*) of advanced study efforts will receive only cursory mention for comparison purposes. Two of the mission modes in particular received the greatest share of analytical effort: (1) Extended Staytime Apollo (Augmented LM; References 3 and 4) and (2) use of intermediate capability launch vehicles.

The extended staytime Apollo assumes a grown LM. The maximum LM weight consistent with Service Module propellant capacity (Block I and II tanks), and launch vehicle injection capability was evaluated from the standpoint of landed and returned payload capability. LM separation weights of 39,500 and 46,500 lbs are possible for Block II and Block I tanks respectively if the present Apollo control weights are considered. The impact of the new heavier Apollo control weights under consideration are shown to reduce these weights to 35,300 and 43,700 lbs for the two Service Module tank capacities.

The range of landed payloads shown for the intermediate launch vehicle (6900 - 9500 lbs) is sufficient to support early lunar explorations. Based on preliminary results of the Early Lunar Shelter study, for example, a 9000 lb landed payload would support 3 men on the lunar surface for about 21 days with 3300 lbs allowed for scientific equipment (experiments plus a small roving vehicle). Figure 1 presents a trade-off curve showing the mission staytime vs scientific payload for 9000 lbs landed on the moon. Landed payloads of

*Lunar Exploration Systems for Apollo

[redacted]

this order could also include combined shelter and mobility systems (MOLAB, MOLEM, etc.) with adequate scientific support landed via a second intermediate launch vehicle. Exploration missions of this nature have the advantage of being able to visit a variety of lunar sites, and at the same time provide a good test for mission equipment required for larger, more permanent type base exploration concepts.

Before taking up the candidate missions, a brief discussion of the flight mechanics involved in determining mission capabilities is needed. The basic rocket equation was applied to selected ΔV budgets to provide comparable performances for the different modes evaluated. The Apollo ΔV budget was used for Apollo type LOR flights. All other missions were based on the two ΔV budgets shown in Table 1. These budgets represent a range from slightly optimistic to moderately conservative, and performances calculated with them have a good chance of bracketing the true capabilities.

2.0 SINGLE VEHICLE MISSIONS USING AVAILABLE OR MINIMUM MODIFICATION EQUIPMENT

2.1 RELAXATION OF CONTINGENCIES

Prior to assembling new logistics equipment into mission modes, the impact of contingency relaxation in the Apollo velocity budget was assessed. The LM ΔV budget is of prime interest because of the direct application to landed payload increases, and thus will be the only budget considered herein.

It would be "guess work" to attempt predicting possible reduction in the LM ΔV budget at this time, but a few examples should provide an awareness of the possibilities. Some representative cases are:

a. Reduction of hover time because of crew experience and relaxed landing criteria.

b. Use of the Service Module to take over some of the propulsion requirements of the LM such as:

(1) Retro to a lower lunar orbit to decrease requirements on the LM for both descent and ascent.

(2) Perform small plane changes required of the LM during descent and ascent.

(3) Perform the return rendezvous and docking maneuvers.

Figure A-1, as explained in Appendix A, indicates the possible LM weight increases for a range of ΔV budget reductions. The example used in Appendix A might be considered typical for the LOR mission. The ΔV reductions of 200 ft/sec for ascent and 600 ft/sec for descent might come from the following changes to the Apollo mission profile:

a. Selection of a 10 NM instead of 80 NM lunar orbit altitude would reduce ΔV's for both ascent and descent by 200 ft/sec.

b. Reduction in hover time by 75 seconds would further reduce the descent ΔV requirement by 400 ft/sec.

As determined from Figure A-1, these adjustments could increase the landed "non-returnable" payload by 2,150 lbs, or with about 1900 lbs increase in landed payload, allow for 229 lbs additional return payload (lunar samples).

This increased capability is available without change to the Apollo LM, except for integration of the increased payloads. For the above example, the lunar staytime for the Apollo type mission could be extended 4-5 days and still allow landing over 1000 lbs of scientific equipment for support (estimate based on 250 lbs/day as weight of expendables required for staytime extension).

2.2 EXTENDED STAYTIME APOLLO

A reasonable possibility for extending the Apollo capability would be to use the available SM propellant capacity. With the CSM inert weight at the Apollo level (21,200 lbs), use of 40,000 lbs of SM propellant (Block II tank capacity) would enable a LM separation weight of 39,500 lbs. The launch vehicle translunar injection (TLI) capability required would be 104,000 lbs - within the assumed 1970 Saturn V capability (References 1 and 2).

These results look promising; simply filling the SM tanks to capacity and modestly upgrading the launch vehicle allows a 7000 lb increase in LM separation weight. The concept must be examined, however, from the standpoint of LM modifications required to take advantage of the weight growth. Two sample cases will be discussed briefly to provide a feel for some of the problem areas involved.

First consider the case where the thrust level of the descent engine is increased sufficiently to provide the same initial thrust-to-weight ratio (T/W) at the start of the descent maneuver. The engine burn time and gravity losses would then be the same and hence, the descent ΔV budget would not change*. The landed weight would be 18,400 lbs and 21,100 lbs of descent propellant would be used (3,740 lbs over the present tank capacity). Modifications to the descent stage for additional tankage, increased engine weight, and structural reinforcement (landing gear, etc.) would increase its inert weight by about 1000 lbs based on maintaining the Apollo usable propellant weight to total stage weight ratio. The net increase in landed payload over Apollo would be about 2200 lbs (left on the lunar surface).

If the larger LM were used to increase the weight of lunar samples for earth return, the interplay between modules is a little more complex; some of the SM propellant is required for return of the samples, and thus the allowable LM separation weight must be reduced. A case was assumed where the increased return payload weight equaled the increase in landed payload. The allowable LM separation weight for this case was 38,300 lbs, and the landed and return payload weights could be increased by 850 lbs over the Apollo capability. The increase in landed weight (excluding the spent descent stage) would be about 1850 lbs, but about 1000 lbs of this is additional ascent stage propellant and tankage required for returning the samples to lunar orbit. Greater return payloads are possible if the landed payload weight is reduced (up to 1400 lbs if no addidional payload is landed), however, the assumed case seems more realistic.

The above heavier LM requires redesign to provide increased tankage, landing structure and engine thrust levels. Candidate LM augmentation techniques are described in Reference 3, and a comparison with the AAP shelter-taxi approach is discussed in Reference 4.

Summarizing the two cases considered here, a 7000 lb increase in LM separation weight is possible if the Block II SM propellant capacity is used. The relatively large weight growth amounts to about 2200 lbs additional landed payload for surface operations. If increased return payload were the major objective, a 5800 lb LM weight increase (constrained by SM propellant capacity) would provide an 850 lb increase in both landed and returned payload over the Apollo capability.

If Block I SM tanks were used for the two cases above, a maximum LM separation weight of 46,500 lbs would be possible. The LM weight is now limited by the launch vehicle TLI capability rather than by the SM propellant capacity. (Uprated Saturn V capability assumed to be 114,000 lbs per

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*This is not necessarily the best way to improve the stage, but simply the easiest case for a first analysis.

references 1, 2, and 5). The comparable payload improvements would be 4500 lbs landed or 1950 lbs landed and returned. These results are tabulated in Table 2.

Recent indications are that the Apollo control weights may be revised to reflect a 98,000 lb injection weight. A breakdown of these new weights (Reference 6) indicates substantial increases to the Command and Service Modules' inert weights, and consequently to the amount of Service Module propellant required for the Apollo mission. If these weights are incorporated, the effects are rather drastic. The maximum LM separation weights possible with the Block II service module (40,000 lbs of propellant) would be reduced from 39,500 lbs to 35,300 lbs. With an uprated Saturn V and a Block I Service Module, the allowable LM separation weight would be reduced from 46,500 to 43,700 lbs. Table 3 corresponds to Table 2 except that the increased Apollo weights are reflected.

Appendix C contains the methods used for calculating the results presented here.

2.3 EARTH ORBIT RENDEZVOUS MODE

Previously it was shown that a substantially heavier LM could be flown by using the Service Module's full propellant capacity. The launch vehicle injection capability required, however, was 104,000 lbs. In the event that the Saturn V vehicle capability does not grow to this level, another alternative, the earth orbit rendezvous mode (Reference 7), could enable assembly of an uprated Apollo, but at the expense of an uprated Saturn I launch vehicle. The mission requires both a Saturn V and Saturn I launch. The Saturn I vehicle (40,000 lbs earth orbital capability) places a heavier unmanned LM into earth orbit. The Saturn V vehicle orbits a standard manned CSM which rendezvous and docks with the orbiting LM. Translunar injection is accomplished by the S-IVB stage of the Saturn V vehicle. Because of the lighter payload on the Saturn V vehicle, sufficient propellant remains in the S-IVB stage to inject 116,000 lbs. This capability, derived by Douglas Aircraft Co, (Reference 7), is more than adequate to allow for some CSM weight growth.

The LM gross weight would be about the same order of magnitude as previously discussed (39,000 lbs) and thus the landed or returnable payloads would be the same as presented in the previous mission mode.

The "Earth Orbit Rendezvous" mode is mentioned here merely as a possible contingency in event the Saturn V vehicle improvements fail to materialize.

3.0 TWO-VEHICLE MISSIONS USING AVAILABLE OR MINIMUM MODIFICATION EQUIPMENT

The mission modes discussed up to this point have been confined to a single vehicle* carrying both personnel and logistics for the mission--essentially, an extension of the Apollo capabilities.

The next step will be to look at two-vehicle missions, with one launch used primarily as a personnel carrier and the other for logistics. For the remaining mission modes to be discussed, the Saturn V Apollo configuration will be used for delivery and return of personnel via the Apollo type LOR flight. With modest upratings, the capability of this system can be extended to land and return three (3) men; the maximum considered for this study. Thus, all the following mission modes discussed will be confined to the logistics flights.

3.1 UNMANNED APOLLO WITH LM LANDING

If the basic Apollo hardware were flown on an unmanned "no return" flight, a substantial logistics payload would be possible via an unmanned LM landing. Larger payloads are realized primarily because the SM "earth return" propulsion can be used to accomplish part of the descent. The ΔV requirements for the LM descent stage are thus reduced allowing off-loading of propellant and substitution of payload. Based on the Apollo spacecraft control weights (94,000 lbs), but with the Block II Service Module tanks filled to capacity, the total landed weight, including the spent descent stage, would be between 19,500 and 21,000 lbs. Subtracting the weight of the spent descent stage leaves between 14,500 and 16,000 lbs of payload. For the case of minimum modification hardware, the LM ascent stage would have to be carried primarily for its reaction control and guidance systems. Allowing 5,000 lbs for an ascent stage stripped of all but essential components decreases the net usable payload to between 9,500 and 11,000 lbs. Use of the LM Truck concept with the "no return" mission would allow a payload package to replace the ascent stage except for a docking structure. The usable payloads could then be increased by about an additional 4,000 lbs.

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*The Earth orbit rendezvous is classified as a single vehicle mission in the sense that only one vehicle is involved beyond the earth orbital assembly phase.

These capabilities were derived using the Apollo CSM inert weights. Since the CSM will not contain a crew and is jettisoned rather than returned to earth, it can be stripped of all but equipment essential to this type mission to further increase the usable payloads (175 lb payload increase for each 1000 lbs inert weight removed from CSM).

This mission mode looks attractive from the standpoint of making use of existing Apollo hardware; however, there are some problem areas. Flying the basic Apollo type mission sequence requires a turn-around and docking maneuver after translunar injection. This maneuver would have to be automated for the unmanned mission mode. Use of on board TV systems with a command link to earth seems a reasonable solution, but would require some development and test. The guidance and navigation systems of Apollo would also require some additional features for an unmanned landing. Finally, the descent staging concept would have to be implemented.*

4.0 MISSION MODES USING MODIFIED AND NEW EQUIPMENT

4.1 INTERMEDIATE LAUNCH VEHICLES

Launch vehicles of intermediate capability were investigated to determine their application to a lunar exploration program. Two vehicles with capabilities that could very well fit into a spectrum of early missions were selected. The primary advantage of the intermediate class vehicles is their lower operational costs.

The two launch vehicles selected were the Saturn IB 11.7A(T)** with a 116,000 lb earth orbital capability, and the MLV-INT-20** with a 135,000 lb capability. The Saturn IB 11.7A(T) is an uprated Saturn I vehicle with four 120 inch, 7 segment, tailored grain, solid rocket motors strapped on to the first stage which has a 20 foot tank extension. The MLV-INT-20 vehicle essentially is a Saturn V vehicle with the second stage (S-II) removed and with only 4 F-1 engines in the first stage.

The following translunar injection (TLI) capabilities for these two vehicles were estimated on the basis of data received from Douglas Aircraft Co. (DAC) for the Saturn IB 11.7A(T) and from preliminary trajectory calculations made for the MLV-INT-20:

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*A study of this concept might have useful, long-range implications.

**Launch vehicle nomenclature taken from Saturn improvement studies.

Saturn IB 11.7A(T) - 31,375 lbs TLI

MLV-INT-20 - 35,000 lbs TLI

The lunar landed payloads possible with these two vehicles were first determined on the basis of using a cryogenic landing stage (RL-10 engine performance) sized such that the weight of the stage plus the payload equaled the TLI capability. The landed payloads were:

Saturn IB 11.7A(T) - 8,100 - 9,200 lbs landed

MLV-INT-20 - 9,000 - 10,250 lbs landed

A TRW study (Reference 8) presented some design concepts of both single and two stage cryogenic landers for payloads in the order of 30,000 lbs with the Saturn V vehicle. Use of either of these landing stages with the intermediate launch vehicles was investigated. In addition to performing the retro and landing maneuvers, the basic mission mode employed the cryogenic landing stage to provide the additional impulse to reach injection velocity after launch vehicle (S-IVB burn-out. The landed payload capabilities for either of the landing stages were:

Saturn IB 11.7A - 6,900 - 8,200 lbs landed

MLV-INT-20 - 8,200 - 9,500 lbs landed

The payload penalty of about 1000 lbs is associated with the larger inert weight of the TRW landing stages. This penalty must be traded off against the obvious advantages of using a stage suitable for both the intermediate and Saturn V vehicles. The intermediate vehicles could then be used for the dual purpose of delivering logistics for early, smaller scale missions while serving in the development of a landing stage for larger scale operations.

4.2 LM SHELTER MISSION

This and all the following mission modes use the Saturn V vehicle along with new equipment developments for logistics flights. The following are resumes from the various studies reviewed. References to the studies are included if more detail is desired.

The LM shelter mission (Reference 4) is relatively well known from the AAP program and will be only briefly mentioned here to provide a base for comparing capabilities of the mission equipment to follow. The basic mission concept uses a LM ascent stage converted to provide a shelter capable of supporting a two-man crew in the lunar environment for 14 days. In addition to the shelter, this type of flight is capable of landing a small roving vehicle (LSSM) and 2100 lbs of scientific equipment. The shelter is landed unmanned and the crew is landed nearby in a separate LM modified for a long standby time on the surface.

4.3 LM TRUCK/ELS MISSION

Two new equipment items are required for this type of mission; the LM Truck, and the Early Lunar Shelter (ELS). The LM Truck is a LM descent stage modified to include an RCS system, provide a platform for payload interface, and contain the necessary guidance for an unmanned landing. The landed payload capability is the same order of magnitude as the LM descent stage (approx. 10,300 lbs). The Early Lunar Shelter concept is presently under study to develop an optimum shelter design capable of supporting 2 or 3 men on the lunar surface for an extended staytime. Preliminary results of this study indicate that the ELS could sustain a crew of three (3) on the lunar surface for 30 days or 2 men for 50 days in a duty cycle having nine man-hours per day of 7,300 lbs, which leaves 3000 lbs to be assigned for scientific and mobility equipment (Local Scientific Survey Module and/or Lunar Flying Vehicle).

4.4 S-IVB STAGE CONVERTED TO LANDER (LASS)

The LASS concept (Lunar Application for a Spent Stage) as proposed by Douglas Aircraft Company (Reference 9) uses the S-IVB Stage of the Saturn V vehicle as a lander. Landing is accomplished by means of a highly versatile J-2 size engine with or without two auxiliary RL-10 engines parallel mounted to accomplish touchdown (Figure 3). A landing gear must be added to the stage. Douglas claims a landed payload capability of about 27,000 lbs. In addition, there is the possibility of using the empty S-IVB tankage as a shelter or lab.

A review of this proposal was made (Reference 10) with the general conclusion that the mission mode is feasible. Using a more conservative ΔV budget and heavier landing gear weight reduced the landed payload to a range between 16,000 and 19,000 lbs. Labor on the lunar surface required to convert the S-IVB tankage to a lab or a shelter will probably rule out this idea, especially for single missions to a given location. The vertical landing configuration has a relatively poor length-to-diameter characteristic and could present problems with landing dynamics and cargo unloading.

From a hardware configuration standpoint, the LASS offers a near time means of landing substantial payloads on the lunar surface. Even the lower payload figure (16,000 lbs) would provide capability for many different combinations of the mission and scientific equipment described in this report. However, it is doubtful that the LASS would be cheaper than a new optimized cryogenic lander.

4.5 SERVICE MODULE LANDER

A concept proposed by North American Aviation (Reference 11) uses a modified Service Module as a landing stage (Figure 2). The modifications would include a landing gear, structural reinforcement, and a new throttling engine. The Command Module would be replaced by the payload, and guidance and control function for an unmanned landing would be required. The payload quoted was 11,000 lbs landed with Block I tanks (45,000 lbs of propellant) or as much as 16,000 lbs with a 42 inch extension of the Service Module for increased propellant capacity.

This mission mode offers a means of landing payloads in the 10,000 lb class with a relatively simple spacecraft configuration. Modifications to the Service Module could probably be available in a relatively short time with the landing gear presenting the greatest problem. The size of the payload envelope would be limited by the 154 inch diameter Service Module unless a "hammer head" configuration were used (See Figure 2).

5.0 CONCLUDING REMARKS

Lunar exploration program planning should be aimed toward providing required increases in mission capability within reasonable budget constraints. The capability which will ultimately be required, however, cannot be accurately defined at this time, and will undoubtedly be strongly influenced by the knowledge gained from the initial lunar landings. In short, continuity in the lunar exploration program will depend on selection from the various equipment options prior to having totally firm requirements. The options included in this memorandum, therefore, should be considered with this element of risk in mind.

One of the major problems in mission mode selection for exploration is to evaluate the scientific return of single launch missions to several sites relative to the more complete scientific coverage of fewer sites offered by the dual launch concepts. Although this aspect will not be discussed beyond this brief mention, the importance of developing a good scientific return "yardstick" cannot be over-emphasized.

Of the three single launch vehicle mission modes, the Relaxed ΔV budget and the Earth Orbital Rendezvous Modes can hardly be considered valid equipment options. In the first case, increased capability depends on reduced mission requirements to enable greater payloads with existing Apollo equipment. While such a contingency is conceivable, it should not be depended on. The Earth Orbital Rendezvous mode is merely an alternative in the event increased Saturn V capability fails to materialize, or in case weight growth in the basic Apollo hardware uses up the increase. This mission mode by itself cannot increase lunar mission capability unless some LM uprating takes place.

The LM has practically universal application as a personnel delivery system. Further most studies indicate requirements for 3 men on the lunar surface. Landing and returning a third crew member will require LM uprating, and the associated development costs will be incurred. Maximum LM uprating consistent with launch vehicle and service module capabilities probably would not increase the development costs appreciably. Figure C-1, Appendix C, indicates the range of capabilities possible in terms of landed and return payload increases for maximum LM upratings consistent with two levels of Saturn V capability and with either Block II or Block I Service Modules. Figure C-1 also indicates the effects of the proposed Apollo control weights consistent with a 98,000 lb injection weight. It can readily be seen from Figure C-1 that the Apollo spacecraft weights must not be allowed to grow with increasing launch vehicle capability if the LM growth potential for lunar exploration activities is to be maintained.

All remaining mission modes deal with the unmanned logistics flights of the dual launch concept. The primary differences are in the choice of landing vehicles. The unmanned Apollo with LM landing introduces some rather severe mission complexities (Automated turn around and dock and descent staging of the Service Module). The LASS and Service Module Lander involve converting either the S-IVB stage or the Service Module into landers. Costs associated with the rather extensive modifications could well be comparable to the development of an optimized cryogenic lander. The LM Truck probably would be the least expensive to develop.

The Intermediate Launch Vehicle concept provides a means of delivering lunar logistic Payloads with a smaller launch vehicle and a new cryogenic lander. The lander developed here would be designed for eventual use with the Saturn V vehicle and payloads in the 30,000 lb class. The high development costs associated with the new launch vehicle configuration and the lander would be gradually offset by the lower operational costs (the break-even point with dual Saturn V launch missions comes at about 10 expeditions).

Aside from providing development of the lander, this mission mode has other side benefits. Use of the Saturn I derived intermediate launch vehicle reduces requirements for Saturn V vehicles and facilities in event of competition with other space programs. In addition, the lower operational costs are especially attractive with multiple launch missions (two intermediate vehicles for logistics and one or more Saturn V's for personnel). The added launch would be used to deliver a mobility system of the MOLAB class to provide more extensive surface exploration.

C. Bendersky

C. Bendersky

D. R. Valley

D. R. Valley

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1012 DRV

Attachments
Tables 1-3
Appendixes A-C

REFERENCES

1. Bendersky, C., and D. R. Valley, "Launch Vehicle Engine Performance During Final Phases of AAP Program", Bellcomm Memorandum For File, CONFIDENTIAL, April 6, 1966.

2. "Effects of Propulsion System Characteristics on Saturn V Escape Payload Capability" LAPR-63-151-Rocketdyne Division of NAA Inc., (Internal Report), December 16, 1963.

3. "Apollo Applications Program Preliminary Definition Study for Utilization of LM", Progress Review, GAEC, June 16, 1966.

4. Waldo, J. E., "Description of an Augmented LM and Comparison with the AAP Shelter/Taxi Approach," Bellcomm Memorandum For File, CONFIDENTIAL, October 19, 1966.

5. "F-1 Uprating Study - Final Report", Rocketdyne Division of NAA, January 26, 1965.

6. "Apollo Lunar Landing Mission Symposium", Proceedings and Compilation of Papers, Volume 1, Manned Spacecraft Center, June 25 - 27, 1966.

7. Letter to W. D. Green, MLA, from T. J. Gordon, Douglas Aircraft Company, Subject: Saturn IB/Apollo Performance Increases Through LM Rendezvous Mode, December 30, 1965.

8. "A Comparative Design Study of Modular Stage Concepts for Lunar Supply Operations"; 4 Volumes, CONFIDENTIAL, TRW; December 12, 1963.

9. "Lunar Applications of a Spent S-IVB Stage (LASS)", Douglas Aircraft Company; September, 1966.

10. Bendersky, C., "Critique of LASS Concept", Bellcomm Memorandum For File; March 16, 1967.

11. "Advanced Lunar Transports and Logistics Vehicle Concepts AS66-3, S&ISD of NAA, Revised Briefing; April, 1966.

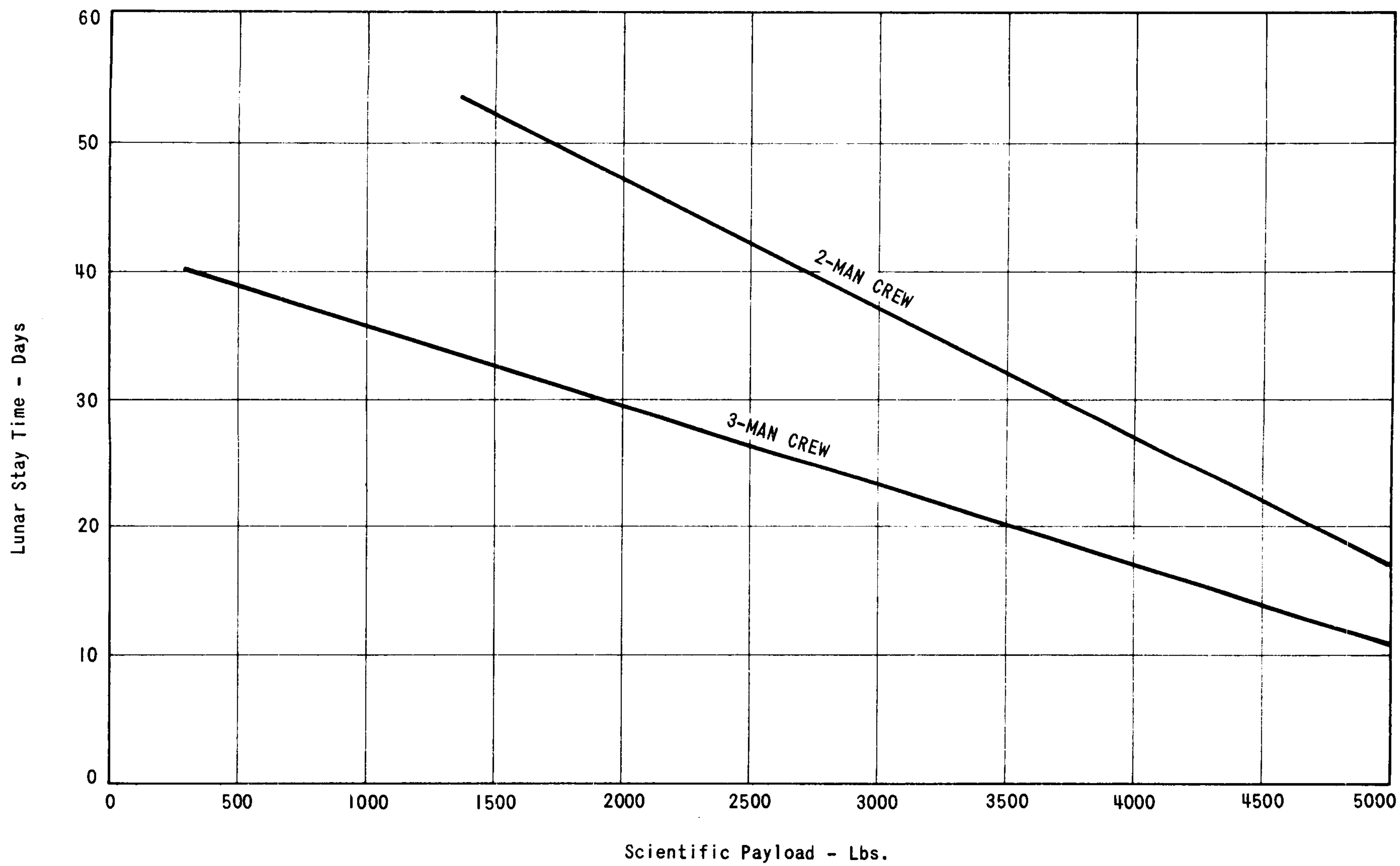
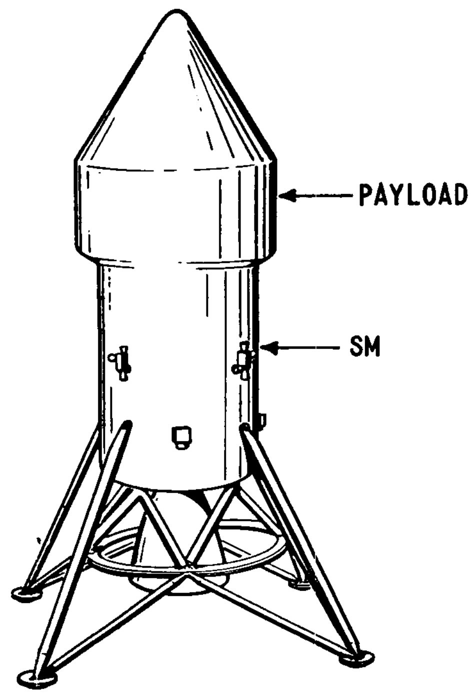


FIGURE I - LUNAR STAYTIME VS. SCIENTIFIC PAYLOAD FOR 9000 LBS. LANDED CAPABILITY (BASED ON ELS DUTY CYCLE - 9 HRS/DAY EVA) CRYOGENIC STORAGE OF H_2 & O_2



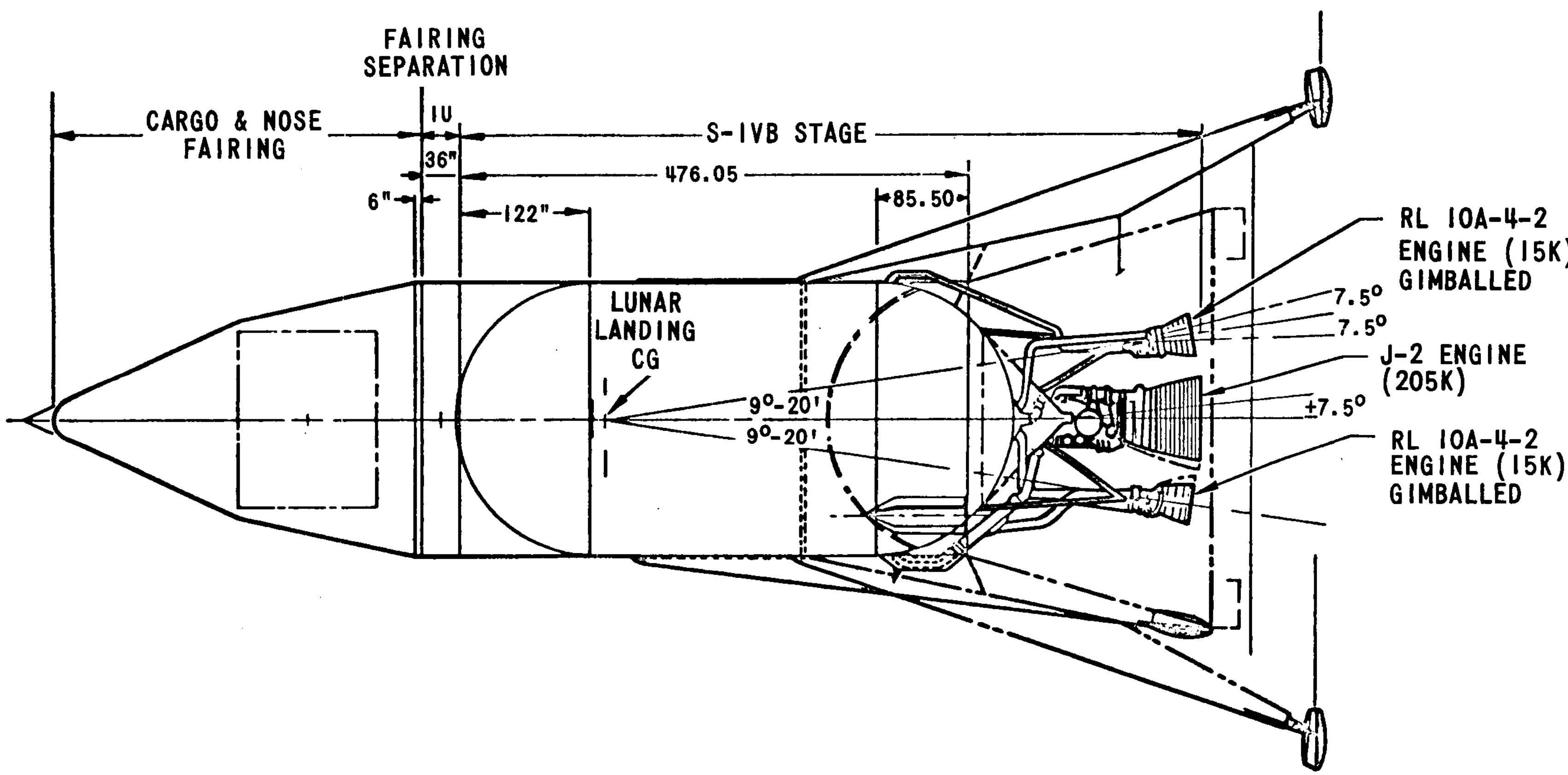
FEATURES

- SIMPLE MISSION CONFIGURATION
- STRAIGHTFORWARD DEVELOPMENT
- SUBSTANTIAL PAYLOAD CAPACITY AT EARLY OPERATIONAL DATE
  - 11,070 LB LANDED WITH BLOCK I SM
  - 16,400 LB WITH EXTENDED SM

PROBLEM AREAS

- EXTENDED VERSION REQUIRES 42 IN. LENGTH ADDED
- DESIGN LANDING GEAR & THROTTLING ENGINE PROVISIONS
- REMOTE GUIDANCE & CONTROL

FIGURE 2 - EARLY DIRECT MISSION LOGISTIC SM LANDER



NOTE: GUIDE RAILS NEEDED TO PROVIDE RL 10A-4-2 CLEARANCE WITH INTERSTAGE SEPARATION.

FIGURE 3 - LASS (LUNAR LOGISTICS VEHICLE) MODIFICATION OF S-IVB J2-S/2-RL-10 CONFIGURATION

APPENDIX A

Figure A-1 indicates the LM weight performance for various degrees of relaxation in its ΔV budget. The range of ΔV reductions (500 ft/sec for ascent and 800 ft for descent) is sufficient to reduce the Apollo LM velocity requirements to a minimum and still have the resulting vehicle weights remain within the capabilities of the Block II SM and the 1970 Saturn V launch vehicle.

The curves of Fig. A-1 are based on the Apollo LM control weights, tank capacities, and engine performance. Allowable increases to both the LM ascent and descent stages can be read from the family of curves for combinations of LM ΔV adjustments. Reducing the ascent ΔV budget can be taken advantage of in two different ways: (1) adding to the ascent stage burnout weight (sample returns), or (2) off-loading ascent propellant and substituting payload. Accordingly, there are two curves for each increment of change in the ascent ΔV.

To help interpret Fig. A-1, let it be assumed that the ascent ΔV is reduced by 200 ft/sec, and the descent by 600 ft/sec. Following each of the two curves labeled - 200 (ascent ΔV adjustement) to intersection with the 600 ft/sec descent ΔV reduction shows that 2150 lbs can be added to the descent stage if ascent propellant is off-loaded (dashed curve) or that only 1720 lbs can be added if the ascent stage burn-out weight is increased. The allowable weight of ascent propellant off-loaded (210 lbs) or the increase in ascent stage burnout weight (229 lbs) are indicated as part of the curve labels.

Descent stage weight increases can be considered as increased landed payload, while increases to the ascent stage burn-out weight can be interpreted as both landed and returned payload increases.

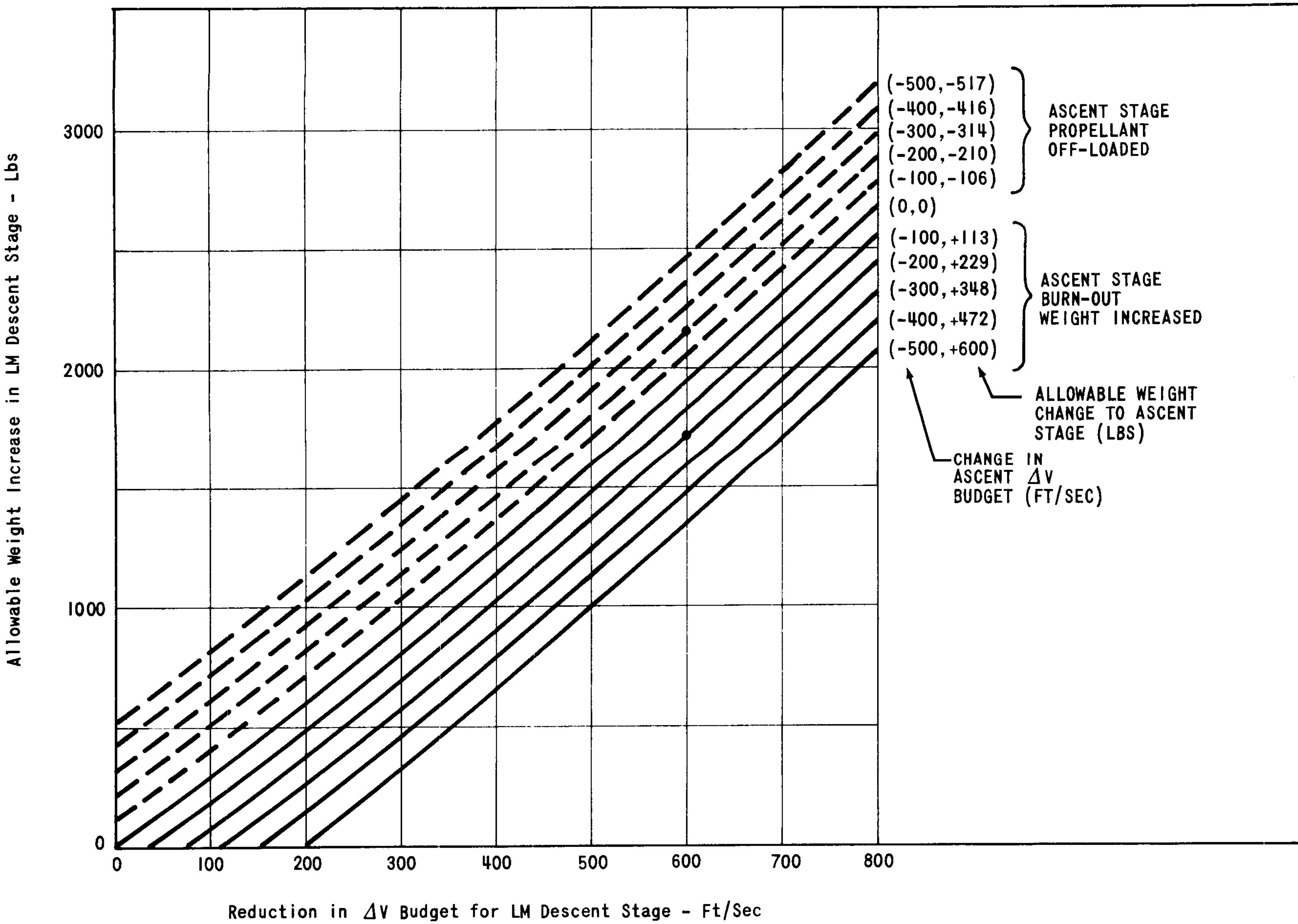


FIGURE A-1 - EFFECT OF LM ΔV BUDGET RELAXATION (BASED ON HOLDING LM DESCENT PROPELLANT CONSTANT AT THE APOLLO VALUE AND NEVER EXCEEDING THE ASCENT STAGE PROPELLANT CAPACITY)

APPENDIX B

Figure B-1 was developed in the process of determining the LM growth possible by using the entire SM propellant capacity. The figure is being included here for its convenience as a tool in estimating weight performance.

Basically, this chart represents the performance capability of the Apollo SM parametrically related to the CSM inert weight, total LM weight, and total injection weight. To illustrate the use of Fig. B-1, the basic Apollo mission can be taken as an example. The 94,000 lbs injection weight ordinate intersects the solid and dashed lines labeled with the CSM inert weight (21,200 lbs) at points that indicate a LM separation weight of 32,500 lbs and an SM propellant requirement of 37,100 lbs respectively, which is reasonably close to the Apollo numbers. Now, if the CSM inert weight were to increase to 23,000 lbs, the chart can be used to determine the following alternatives:

1. Maintaining the 94,000 lb injection weight allows a LM separation weight of only 29,800 lbs and the SM propellant required would be 37,900 lbs. (Reading vertically on the 94,000 lb injection weight ordinate to the intersections with solid and dashed lines labeled 23,000).

2. Maintaining a 32,500 lb LM separation weight would increase the injection weight to 97,800 lbs with 39,000 lbs of SM propellant required. (Reading horizontally until the 32,500 lb LM weight line intersects the solid (23,000) line and then vertical to dashed line for 23,000 lb CSM.

TABLE I

ΔV BUDGETS

Velocity Required for 70-90 Hour Transfer Trajectory -	35,900 ft/sec
Orbital Velocity for 100 NM Earth Orbit	25,580 ft/sec
ΔV Required for Translunar Injection	10,320 ft/sec

ΔV REQUIRED FOR LANDING

	*TRW (ft/sec)	**MSFC (ft/sec)
Midcourse Correction	112	164
Attitude Control	10	--
Ullage	10	--
Lunar Orbit Insertion	3068	3380
Transfer Orbit Insertion	100	98
Plane Change	--	197
Ullage	10	--
Main Braking	5810	5750
Hover and Land	590	655
Reserves	--	197
Total	9710	10441

*Obtained From Reference 8

**Obtained Verbally From MSFC - Mr. G. Woodcock - R-FP.

TABLE 2

LM Growth Possibilities

as constrained by present control weights and:

(1) Service Module propellant capacity or

(2) Launch vehicle injection capability

	BLOCK II SM PROPELLANT TANKS		BLOCK I SM PROPELLANT TANKS	
	Case I	Case II	Case I	Case II
LM Separation Weight (lbs) (Includes Crew & Payload)	39,500	38,300	46,500	45,700
Injection Weight * (lbs)	103,900	102,800	114,000	114,000
SM Propellant Weight (lbs)	40,000	40,000	43,000	43,000
Landed Payload Increase ** (lbs)	2,200	850	4,500	1,950
Returned Payload Increase ** (lbs)	--	850	--	1,950

Case I - Max. landed payload increase (no additional returned)

Case II - Equal increase in landed and returned payload

---

*Injection weight includes 3,800 lb adapter

**Payload increases to Apollo capability - based on 94,000 lbs injection weight.

TABLE 3

LM Growth Possibilities

as constrained by new control weights and:

(1) Service Module Propellant Capacity or

(2) Launch Vehicle Injection Capability

	BLOCK II SM PROPELLANT TANKS		BLOCK I SM PROPELLANT TANKS	
	Case I	Case II	Case I	Case II
LM Separation Weight (lbs) (Includes Crew & Payload)	35,300	34,800	43,700	43,000
Injection Weight* (lbs)	102,000	101,500	114,000	114,000
SM Propellant Weight (lbs)	40,000	40,000	43,600	44,300
Landed Payload Increase** (lbs)	900	350	3,600	1,550
Returned Payload Increase** (lbs)	--	350	--	1,550

Case I - Max. Landed Payload (no additional returned)

Case II - Equal increase in landed and returned payload

*Injection Weight Includes 3,900 lb Adapter

**Payload Increases over Apollo capability - based on proposed Apollo Control Weights - 98,000 lbs injection weight.

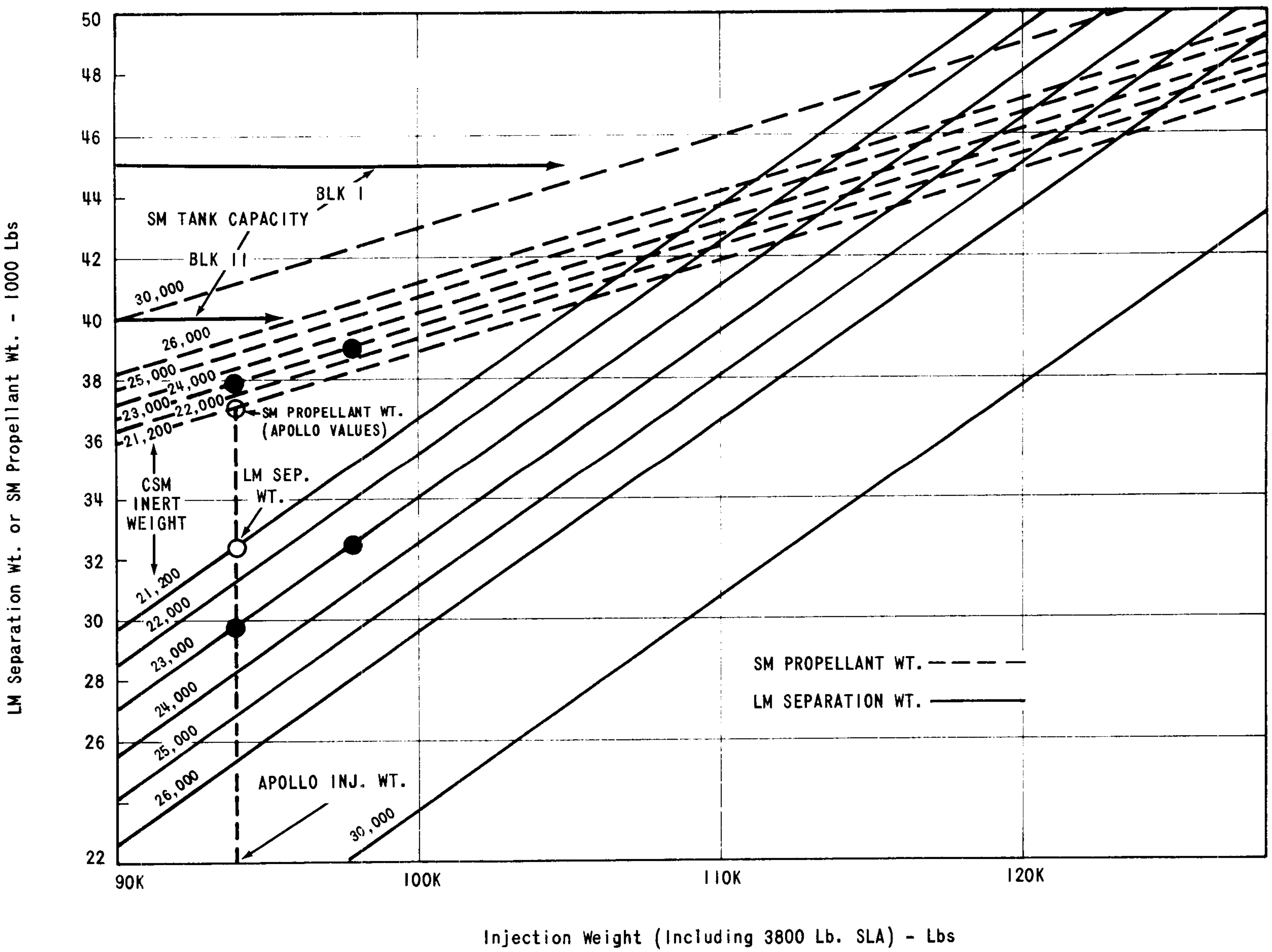


FIGURE B-1 - SERVICE MODULE PERFORMANCE CAPABILITY RELATING SM PROPELLANT REQUIREMENTS TO CSM INERT WEIGHT, LM SEPARATION WEIGHT, AND INJECTION WEIGHT

APPENDIX C

PAYLOAD CAPABILITY OF AN UPRATED LM

I. INTRODUCTION

These calculations determine the increase to Apollo payload capabilities obtainable with a LM uprated to take advantage of Service Module propellant capacity (BLK I and BLK II tanks) and a Saturn V translunar injection capability up to 114,000 lbs.

LET:

ΔLM = LM weight increase over Apollo
ΔSMP = Service Module Propellant Increase Over Apollo
λ = Mass Fraction of the Apollo LM Descent Stage (Weight of Propellant/Total Stage Weight)

LET:

R_1 = Mass Ratio for the Translunar Injection ΔV (3,190 fps)

R_2 = Mass Ratio for the LM Rescue ΔV (680 fps)

R_3 = Mass Ratio for the Lunar Orbit Insertion ΔV (3,607 fps)

R_4 = Mass Ratio for the LM Descent and Landing ΔV (7,332 fps)

R_5 = Mass Ratio for the LM Ascent ΔV (6,586 fps)

$$\text{Mass Ratio (R)} = \frac{\text{Initial Weight}}{\text{Final Weight}} = \text{Exp}\ \frac{\Delta V}{g_o I_{sp}}$$

LET:

X = Δ Payload Landed

Y = Δ Payload Returned

Assumptions:

1. The thrust of the descent and ascent stages are increased to maintain the same initial thrust-to-weight ratio and thus the same ΔV budget.

2. The Apollo LM descent stage mass fraction (λ) is held constant to allow for increased weight of tankage, structure, landing gear, etc., as the descent propellant requirement increases.

3. The increased weight of the ascent stage for tankage and structure is assumed to be 10% of the increase in returned payload (Y).

II. DETERMINATION OF ADDITIONAL SERVICE MODULE PROPELLANT (ΔSMP) REQUIRED FOR LM GROWTH (ΔLM), INCREASED LANDED PAYLOAD (X) AND INCREASED RETURNED PAYLOAD (Y)

(Propellant Weight = (Stage Final Weight)(Mass Ratio-1)

$Y(R_1-1)$ = ΔSMP for transearth injection

$Y(R_1-1)(R_2-1)$ = ΔSMP for LM Rescue

$[Y(R_1-1) + Y(R_1-1)(R_2-1) + \Delta LM + X][R_3-1]$ = ΔSMP for lunar orbit insertion

$\therefore$ Total increase in Service Module Propellant

$$\Delta SMP = Y(R_1-1) + Y(R_1-1)(R_2-1) + [Y(R_1-1) + Y(R_1-1)(R_2-1) + \Delta LM + X][R_3-1]$$

$$\Delta SMP = Y(R_1-1)R_2R_3 + X(R_3-1) + \Delta LM(R_3-1)$$

Using Apollo ΔV budget and performance numbers (I_{sp}) for values of R_1, R_2, and R_3:

(1) $\Delta SMP = Y(0.5704520148) + (X + \Delta LM)(.430716944)$

III. DETERMINATION OF INCREASED LM WEIGHT (ΔLM) REQUIRED IN TERMS OF INCREASED LANDED (X) AND RETURNED (Y) PAYLOADS

$Y(1.1)(R_5)$ = Increased lift-off weight of ascent stage (0.1Y added to allow for ascent stage tankage penalty)

$Y(1.1)(R_5)-Y$ = Increased landed weight of ascent stage

$\Delta LM + X$ = Increased LM separation weight

$\frac{\Delta LM + X}{R_4}$ = Increase in total landed weight

$\frac{\Delta LM + X}{R_4}(R_4-1)$ = Increase in descent propellant required

By definition $\lambda = \dfrac{\text{Propellant Weight}}{\text{Propellant Weight + Burn-out Weight}}$

or Propellant Weight $\left(\frac{1-\lambda}{\lambda}\right)$ = Burn-out Weight

$\therefore \dfrac{\Delta LM + X}{R_4}(R_4-1)\left(\frac{1-\lambda}{\lambda}\right)$ = Increase in LM descent burn-out weight

(Allowance for increased descent stage inert weight is based on holding the mass fraction (λ) constant at the Apollo value).

Increase in total landed weight = Increase in ascent stage landed weight plus the increase in descent stage burn-out weight plus the increased payload landed.

or

$$\frac{\Delta LM + X}{R_4} = Y(1.1R_5-1) + \frac{\Delta LM + X}{R_4}(R_4-1)\left(\frac{1-\lambda}{\lambda}\right) + X$$

Solving for ΔLM:

$$\Delta LM = \frac{Y(1.1R_5-1)(R_4) + X(R_4-1)\left(\frac{1}{\lambda}\right)}{1-(R_4-1)\left(\frac{1-\lambda}{\lambda}\right)}$$

Using Apollo Values for R_4, R_5, and λ:

(2) $\Delta LM = Y(3.619171002) + X(2.132265403)$

Equations (1) and (2) are general expressions that relate the additional Service Module Propellant Weight (ΔSMP) and the increase in LM Weight (ΔLM) to combinations of landed and returned payload increases.

Three sample cases will be worked to illustrate the application of these expressions to determine the possible payload increases when the BLK II Service Module Propellant tanks are filled to capacity (40,000 lbs).

CASE I Maximum landed payload increase - No Additional Returned Payload.

For this case: $Y = 0$ and equations (1) and (2) become:

(1) $\Delta SMP = (X + \Delta LM)(.430716944)$

(2) $\Delta LM = X(2.132265403)$

Since the Apollo mission requires 37,000 lbs of Service Module Propellant, BLK II Tanks filled to capacity (40,000 lbs) provide 3000 lbs of additional propellant (ΔSMP)

Solving (1) and (2) above when $\Delta SMP = 3000$;

$X = 2{,}224$ lbs additional payload landed

$\Delta LM = 4{,}741$ lbs increase to LM weight

LM Separation Weight = 32,500 + 4741 + 2224 = 39,465 lbs

(Table 2 - Case I gives these results)

CASE II Landed Payload Increase Equals Return Payload Increase

For this case: $X = Y$ and Equations (1) and (2) become:

(1) $\Delta SMP = Y(1.001168598) + \Delta LM(.430716944)$

(2) $\Delta LM = Y(5.751436405)$

Solving (1) and (2) above with $\Delta SMP = 3000$;

$X = Y = 862$ lbs landed & returned payload increases

$\Delta LM = 4{,}960$ lbs increase to LM Weight

LM Separation Weight = 32,500 + 4960 + 862 = 38,322 lbs

(Table 2 - Case II gives these results)

CASE III Maximum Return Payload Increase - No Additional Landed Payload

For this case: $X = 0$; and Equations (1) and (2) become:

(1) $\Delta SMP = Y(.5704520148) + \Delta LM(.430716944)$

(2) $\Delta LM = Y(3.619171002)$

Solving 1 and 2 above with $\Delta SMP = 3000$;

Y = 1409 lbs additional payload returned

ΔLM = 5099 lbs increase to LM weight

LM Separation Weight = 32,500 + 5099 = 37,599 lbs

(This last case was not included in Table 2 since it doesn't seem a practical option).

IV. ONE ADDITIONAL STEP NECESSARY IN THE ABOVE CALCULATIONS IS TO CHECK THAT THE LAUNCH VEHICLE'S INJECTION CAPABILITY IS NOT EXCEEDED

Apollo Injection Weight = 94,000 lbs

Saturn V Capability (1970) = 104,000 lbs

Uprated Saturn V Capability = 114,000 lbs

$\Delta SMP + \Delta LM + X$ = Increase to the Apollo Injection Weight

$\therefore \Delta SMP + \Delta LM + X \leq 104{,}000 - 94{,}000$ for 1970 Saturn V

$\Delta SMP + \Delta LM + X \leq 114{,}000 - 94{,}000$ for uprated Saturn V

For the 3 sample cases above, the injection weight is within the 1970 Saturn V capability; therefore the increased payload and LM weights calculated are limited by the Service Module Propellant Capacity.

When the general expressions are applied for cases involving Block I Service Module tanks (45,000 lbs capacity), the resulting injection weight exceeds the capability of the uprated Saturn V (114,000 lbs). Payload and LM weight increases are therefore limited by the launch vehicle capability. For this situation, 3 equations must be used to determine the allowable weight increases. The Service Module Propellant Increase (ΔSMP) must also be treated as an unknown quantity as follows:

1 $\Delta SMP = Y(0.5704520148) + (X + \Delta LM)(.430716944)$

2 $\Delta LM = Y(3.61917002) + X(2.132265403)$

3 $\Delta SMP + \Delta LM + X \leq 20{,}000$

Applying these three general expressions to the same 3 cases, except with a 45,000 lbs Service Module Propellant capacity will give the results shown in Tables 2 and 3 for Block I SM propellant tanks.

The limits of attainable mixes of landed and returned payload increases under the assumptions in this appendix for Block I and Block II SM Propellant Tanks and both old and new Apollo control weights are shown in Figure C-1.

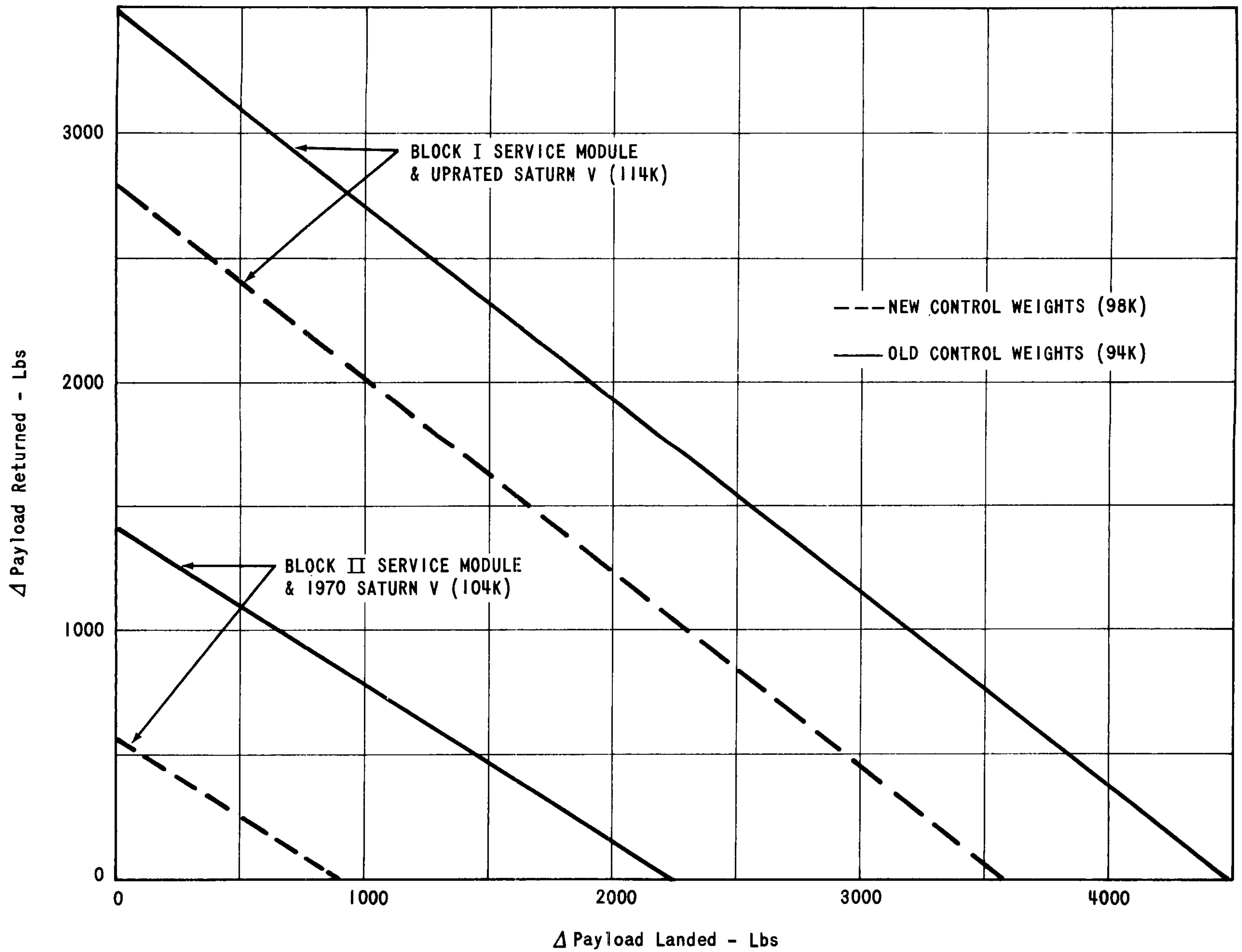


FIGURE C-1 - LM UPRATING POSSIBILITIES